The Delay Time During Depressurization of Saturated Water

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INTRODUCTION

An important phase in the thermohydraulic safety design of light water nuclear reactors involves the determination of the water conditions in the various parts of the primary cooling system during depressurization. In the course of system depressurization; subcooled liquid becomes superheated which eventually flash evaporates. There is a finite time between the saturation state of the liquid and the first appearance of detectable bubbles. This time is termed throughout as the " delay time ". It is a phenomenon that has not recevied enough attention in the literature.

Hooper and Abdelmessih , 1966 carried out depressurization studies in a heated pool of water. They observed (4-8) msec delay time before the appearance of the first bubble in the liquid. Diffusion of dissolved gas towards bubble nucleation sites is thought by Hanbury and McCartney , 1973 to be responsible for the delay time. Kendoush, 1988 showed that the delay times in pressurized water during blowdown were shorter when water was irradiated with fast neutrons than the non irradiated water. El-Nagdy and Harris , 1970-71 appreciated the existence of the delay time but did not record it quantitatively in their experimental system of neutron induced nucleation.

Weisman , et al , 1973 investigated the initiation of water evaporation on metal surfaces during pressure transients. It was found that , for water temperature between 90-150 °C , the wall superheat required to initiate flash evaporation during a rapid pressur transient was significantly higher than required when the pressure was slowly reduced. This result was explained by assuming that a finite time (65 msec-1.6 sec) was necessary for vapour to fill the cavity at which the bubble originates.The experimental results of Kendoush , 1976 produced delay times up to 11 seconds at the top of the downcomer pipe during depressurizations of the circulating Freon-113 system.

Skripov , 1974 believed that metastability , irreversibility and the random nature of the state of superheated liquid are possible causes of the delay time. As part of the nuclear reactor thermohydraulics safety research programme , Edwards , 1968 studied the flow of flashing liquid in large diameter pipes. The theory and calculations of Edwards were based on the use of an arbitrary values for the delay time. Recently , Siikonen , 1983 noticed the nonexistence of a theory to predict the delay time during depressurization. Siikonen attributed the failure of the elaborate computer codes , like RELAP5 and K-FIX to model the exact behaviour of reactor coolant during transients , to the inability of these codes to allow for the delay time in their analytical treatment of the flashing process.

The present study produces new experimental results for the delay time which is encountered during depressurization of saturated and demineralized water.

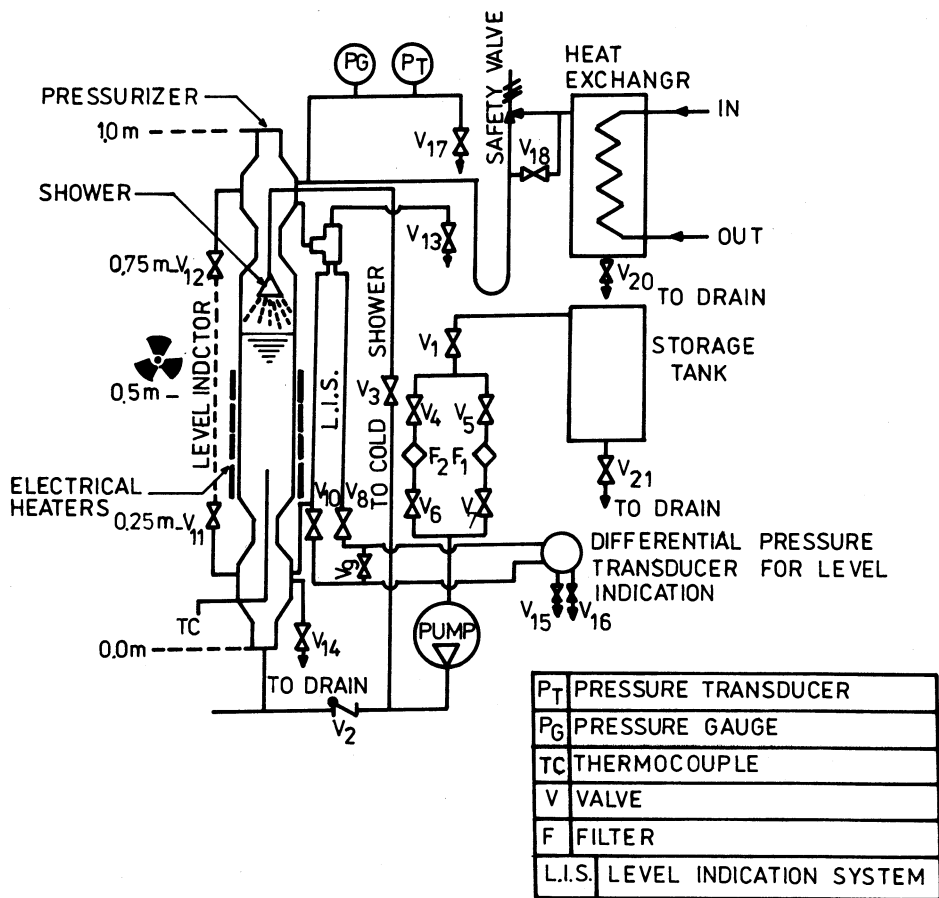|	
P_T	PRESSURE TRANSDUCER
P_G	PRESSURE GAUGE
TC	THERMOCOUPLE
V	VALVE
F	FILTER
L.I.S.	LEVEL INDICATION SYSTEM

Fig. 1 The experimental system.

EXPERIMENTAL SYSTEM

A diagram of the system is given in Fig. 1. The depressurization tests were
carried out in an electrically heated pressurizer 0.072m internal diameter, 2 cm
thickness and 1m in length. The heaters were mounted on the outside surface of
the pressurizer. A displacement pump was used to supply water from a storage
tank to the pressurizer through a set of mechanical filters. At the downstream
of the filters , water either goes into the spray nozzels at the vapour region
of the pressurizer or into the water region at the bottom of the pressurizer. A
high pressure operating needle valve was installed for the control of water in
either branch. Water temperature inside the storage tank was measured by a
thermocouple. The level of water inside the pressurizer was controlled by a
special system of valves and a differential pressure transducer. Monitoring the
temperature of the electrical heaters was done by automatic temperature regulators.
A 5mCi source of gamma rays (type ^{137}Cs) was used for the measurement of void
fraction. The detection of gamma rays was done by an NaI(Tl) scintillation crystal
optically coupled to a photomultiplier tube. The centrelines of the gamma source
and detector were at a plane 57.9cm from the bottom of the pressurizer (Fig.1).
The temperature of water inside the pressurizer was measured with a chromel/alumel
thermocouple. For transient pressure measurement , a transducer was used. The
simultaneous measurement of pressure and temperature during transient allowed the
determination of the degree of nonequilibrium in terms of the difference in
temperature between that measured and the saturation temperature corresponding

to the pressure measurement (Kendoush , 1976).
A safety valve was leading to the vapour region of the pressurizer to prevent any unforseen increase in the pressure. Slow rates of depressurization were initiated by showering cold water spray into the vapour region of the pressurizer. A heat exchanger was used for the condensation of the steam leaving the pressurizer in the fast depressurization tests. All measuring signals were registered continuously with a multi channel galvanometer recorder which gives a visual display on an ultraviolet sensitive paper.

Depressurization by Steam Off-Take

The water was raised to the top of the pressurizer allowing all air to go out of the system. Then the system was pressurized under cold conditions to about 25% above the pressure at which depressurization was to initiate , then the system was examined and any leaks were rectified.
Heat was applied up to the saturation conditions where the upper region of the pressurizer is occupied by vapour and the lower region by water. Fast rates of depressurization were effected through the sudden opening of valve (V18) in Fig. 1 and allowing the steam to escape to the heat exchanger. Valve (V18) is at 2.61m pipe length from the centreline of the pressurizer. The range of initial pressure in these depressurization tests was (0.33-1.45) MPa.

Depressurization by Steam Condensation

When the pressure and temperature of the system reached the desired limit , blow-down was initiated by injecting a shower of cold water into the vapour region of the pressurizer. The condensation of vapour causes a decrease in the system pressure. Slow rates of pressure reduction were obtained in these tests. The range of initial pressure investigated was (1.1-6.0) MPa. The displacement pump was used to supply cold water spray to the pressurizer from the storage tank. Different conditions of initial pressure inside the pressurizer produced different rates of flow of cold water spray. In order to obtain test runs with the same cold water flow rate , it was necessary to calibrate the spray water flow rate against the pump flow rate for different values of initial pressure inside the pressurizer.
Care was taken in both slow and fast depressurizations to avoid bubble nucleation on the inner heated surface of the pressurizer. This was manifested by switching off the electrical heaters, waiting for the system pressure to fall to the desired initial blowdown value and then starting the run by the injection of the cold shower. In this way , it was anticipated that mainly nucleation of bubbles within the bulk of liquid will be recorded.

DISCUSSION

The system normally reaches the state of saturation and thermodynamic equilibrium before depressurization was initiated. In the course of blowdown , bubble nuclei get activated to produce small size spherical microbubbles. When the system reaches the superheated state , bubbles would have grown in size to the degree that they tend to destabilize the thermal equilibrium of the system. The state of thermal nonequilibrium is clearly shown in Fig. 2 , particularly when the saturation temperature falls below the actual water temperature.
The delay time (t_d) was noticed quantitatively from the experimental results of the void fraction as shown in Fig. 3 . It is anticipated that microbubbles start to nucleate at the initial stages of depressurization. Spherical microbubbles of small diameter are formed at their nucleation sites within the liquid. These microbubbles can not be detected by the available nuclear detection system until they grow up and become large enough to be spotted by the scintillation detector. The experimental results of the delay time which is obtained through depressuriz-ation by condensation are shown in Fig. 4 and the results of depressurization by steam off-take are shown in Fig. 5.
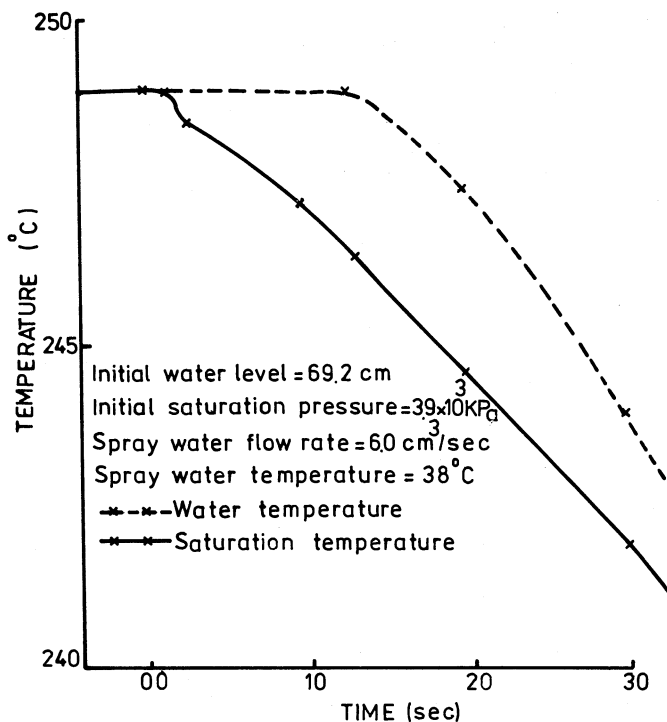
Fig. 2 The variation of the saturation and water temperatures during
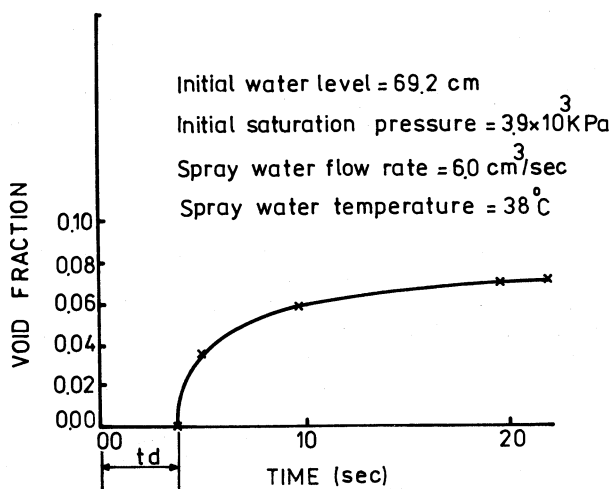slow depressurization.

Fig. 3 The evolution of void fraction during depressurization.
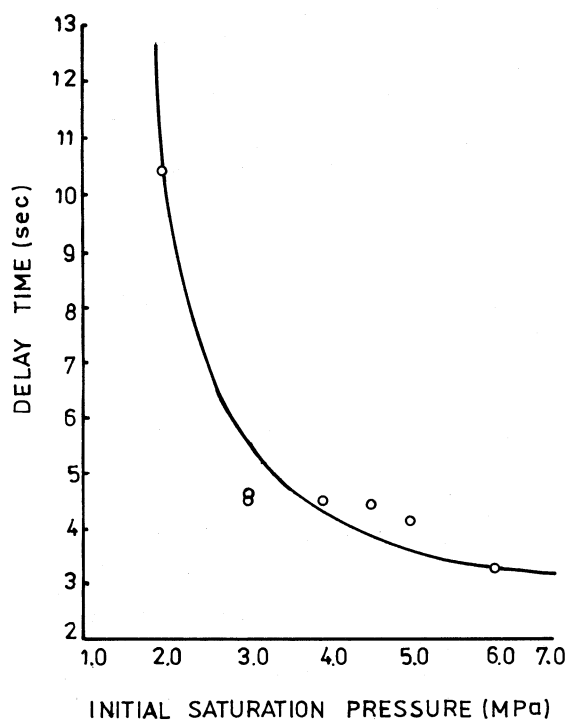
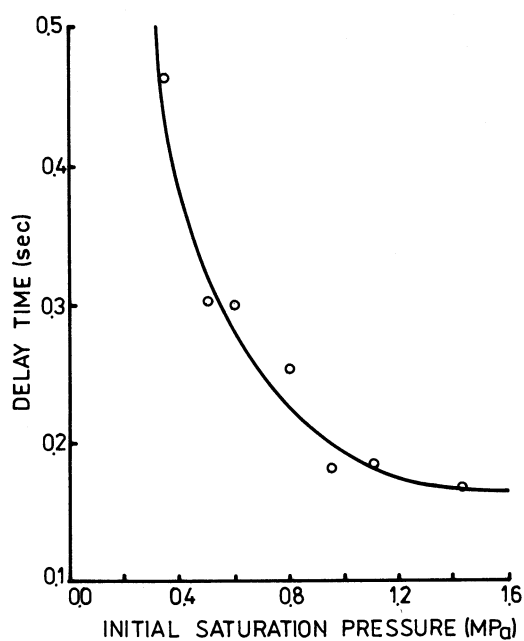Fig. 4 The prediction of the delay time in the depressurization by condensation tests.

Fig. 5 The prediction of the delay time in the steam off-take tests.

CONCLUSIONS

Based on the preceding investigation the following conclusions were drawn :
(1) New experimental evidences were found for the delay time in flash evaporated water during depressurization.
(2) The delay time decreases upon the increase in the initial saturation pressure.
(3) The inclusion of the delay time in the analysis of small break Loss of Coolant Accident (LOCA) may improve the prediction of the pressure , temperature and flow histories of the coolant in nuclear power reactors.

ACKNOWLEDGEMENT

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